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CDMS low ionization threshold experiment

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SuperCDMS Collaboration

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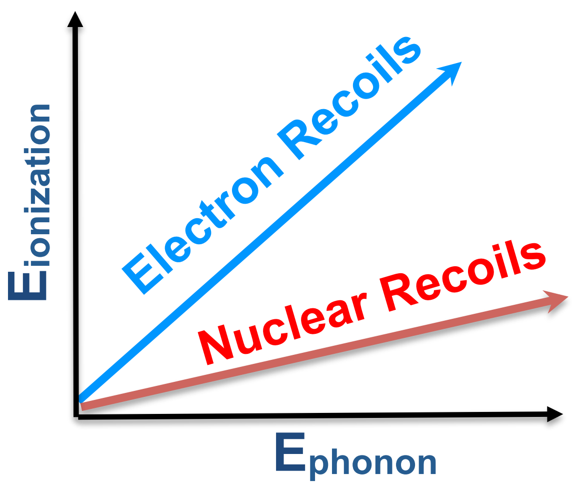
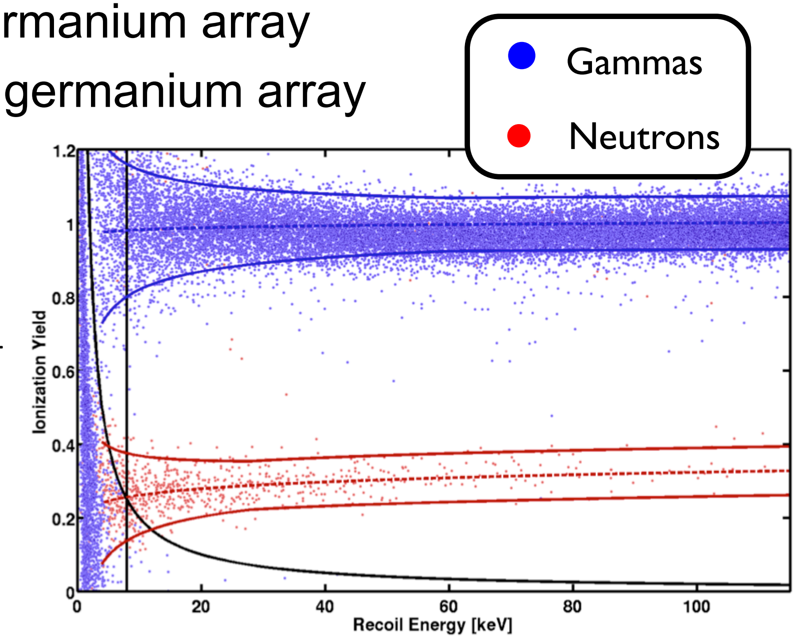
The Cryogenic Dark Matter Search

- The CDMS Collaboration has developed and deployed cryogenic semi-conductor detectors for rare event searches
- CDMS-II at the Soudan Underground Laboratory completed operations in 2009
  - New and interesting results from CDMS-II on LIPs, silicon, annual modulation, …
  - e.g. See D. Speller's poster and J. Billard and R. Nelson's talks from Monday
- SuperCDMS consists of two experiments with substantial detector improvements
  - SuperCDMS-Soudan, an operating 9 kg germanium array
  - SuperCDMS-SNOLAB, a proposed 200 kg germanium array

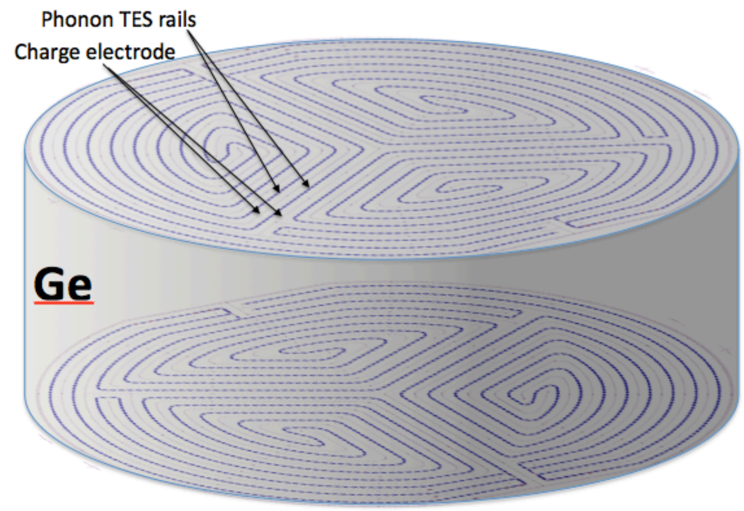


CDMS measures both the heat deposition and the ionization from particle scattering. This allows event-by-event identification the interaction as a nuclear or electron recoil to energies well below 10 keVr.

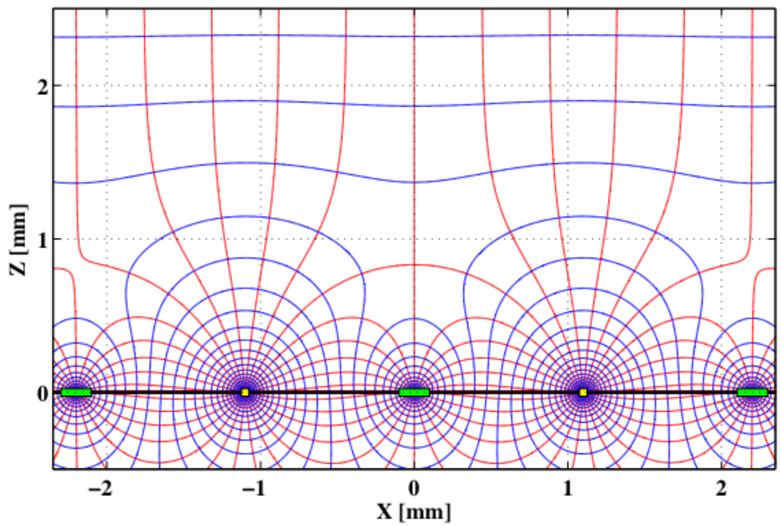


SuperCDMS

- Search with germanium iZIP detectors
- Operating at ~50 mK
  - Enables phonon and charge readout
  - Charge to phonon ratio separates nuclear and electron scatters
- interleaved Z-sensitive ionization and phonon sensors on both faces
  - Surface event identification
  - Outer phonon guard ring



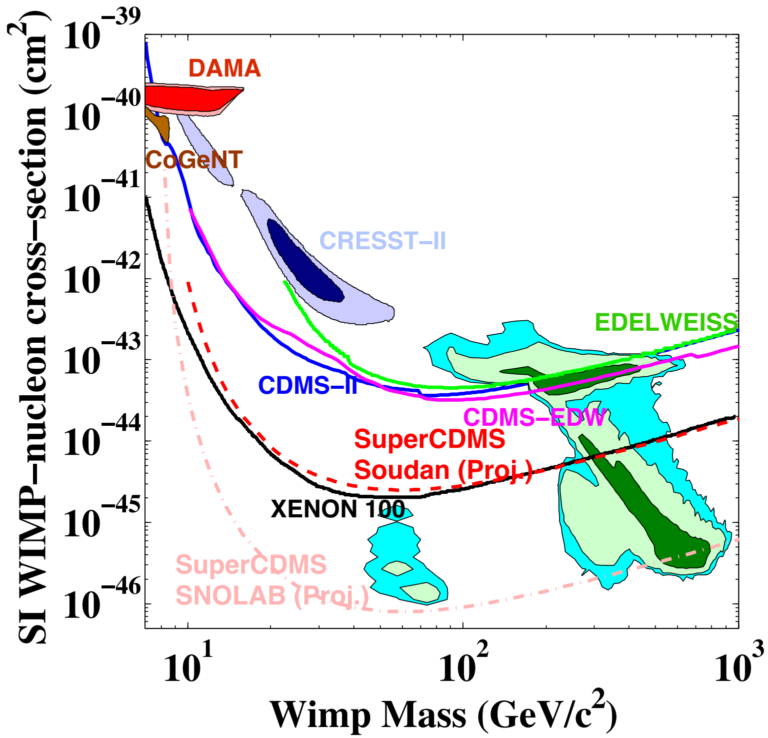
SuperCDMS iZIP detectors have phonon and ionization instrumentation on both faces allowing superior z-sensitivity.



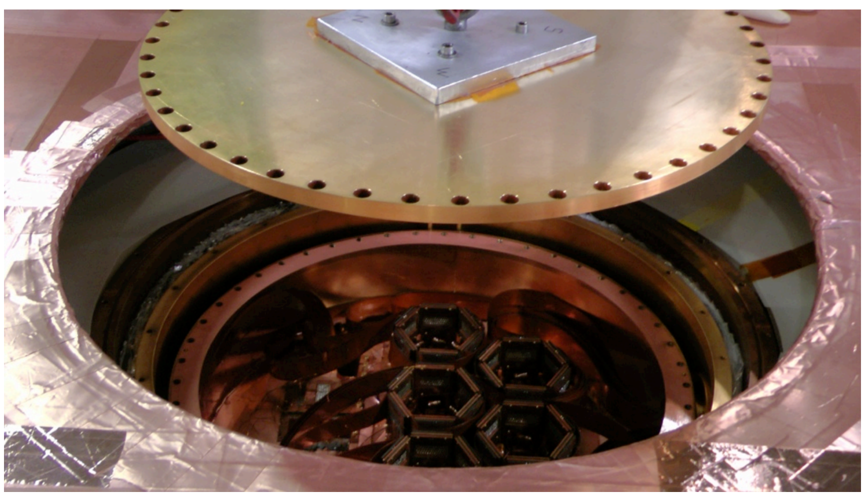
By holding a potential between ionization and phonon electrodes, a more complex electric field is created. Charge near the surface of the detector is collected on only one side. Charge in the bulk of the detector is collected on both faces. See K. Eitel's talk from Tuesday.

SuperCDMS-Soudan

- Array of 15 iZIPs in the Soudan infrastructure built for CDMS-II
- >X10 sensitivity increase over CDMS-II
  - Larger detector mass (x2.5 thicker detectors)
  - Fiducial fraction improved to 67% from 35%
  - Surface background negligible
- See J. Billard talk from Monday for details



Projected WIMP sensitivity for SuperCDMS-Soudan after 3 calendar years (Spring 2015).



SuperCDMS detector installation was completed 8 Nov 2011. Detectors have been operating with final settings since March 2012.

CDMS low ionization threshold experiment

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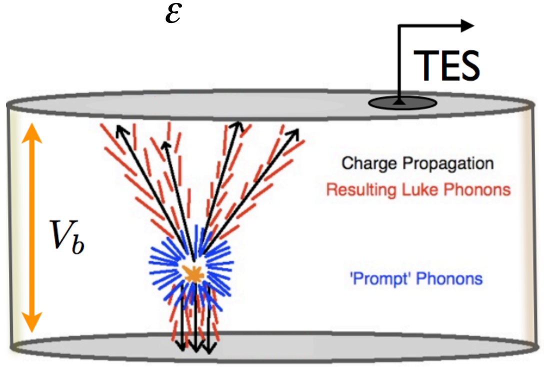
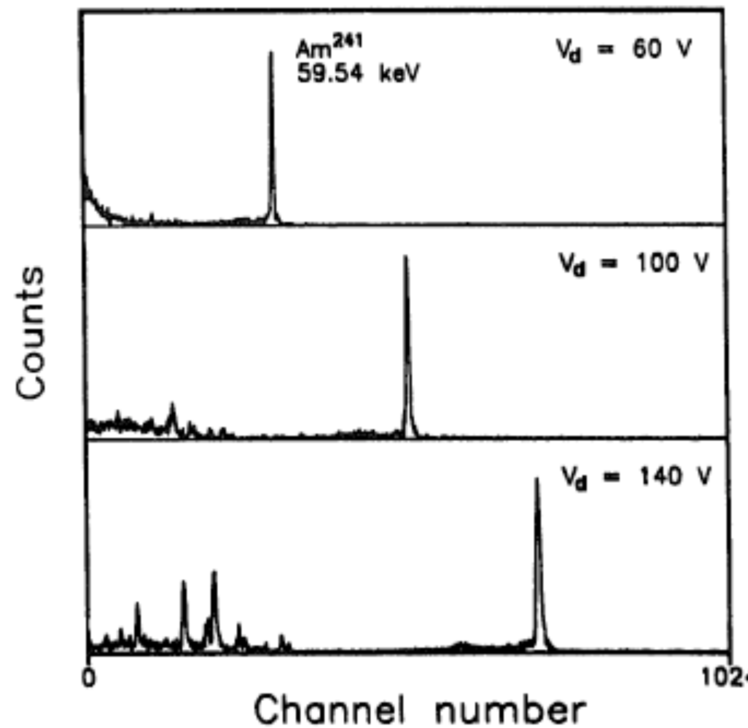
- CDMSlite strategy leverages Neganov-Luke amplification to realize low thresholds with high-resolution
  - Ionization only, no event-by-event discrimination of nuclear recoils
- Drifting N_e electrons across a potential, V, generates qN_eV electron volts of heat

$$N_e = \frac{E_i}{\varepsilon}, \varepsilon = 3eV$$



P.N. Luke et al., NIM A289, 406 (1990)



The work done drifting charge carriers is detectable as heat. This **voltage-assisted calorimetric ionization detection** can improve the energy resolution and threshold of bolometers for ionizing radiation.

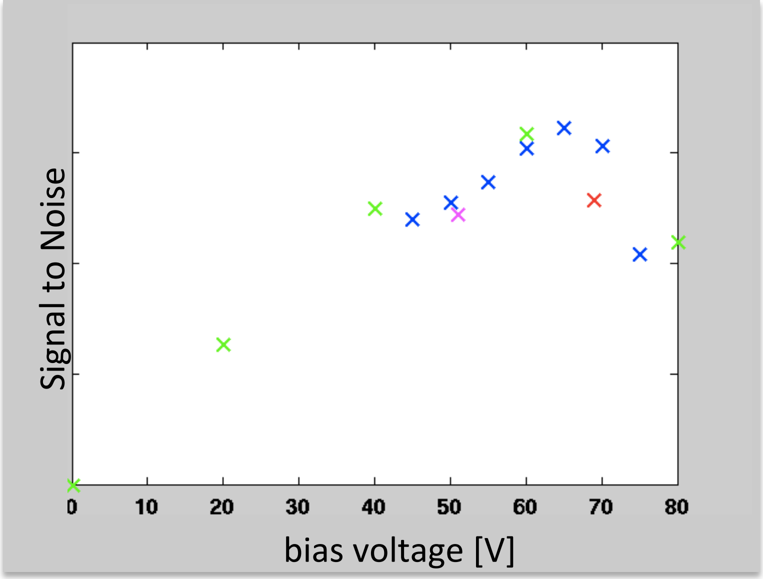
A number of groups have investigated this technique: Neganov and Trofimov (1985), Paul (1988), Paul *et al.* (1990), Spooner *et al.* (1992), Akerib *et al.* (2004), Stark *et al.* (2005), Isaila *et al.* (2012)

CDMSlite - detector

- Custom electronics were implemented
  - Disabling one side of the iZIP and raising that entire side to the bias voltage
- Test runs were taken with a number of iZIPs in early 2012
- One detector, IT5Z2, was selected for an extended run
- The operating voltage was selected by maximizing the signal-to-noise
- The signal gain at 69V is substantial

$$G^* = \frac{E_t(V=69)}{E_t(V=0)} = \frac{1+qN_eV}{1} = 24$$

*** For electron recoils!**



A voltage scan was done on this detector to find the best operating voltage. At low voltages, the signal increases linearly with no change in noise. At high voltage, an onset of leakage current is observed. The leakage current increases the phonon noise reducing the signal-to-noise.

The standard CDMS electronics is only designed to go to 10 V. Custom electronics were required to go to 11 (and beyond.)

CDMSlite - dataset

- Data were taken in three periods in 2012
- One iZIP was used, IT5Z2 – 0.6 kg
  - Selected for its low trigger threshold and low leakage current
- There were two neutron exposures (^{232}Cf)
  - August 22, and August 31
- Raw exposure is 16 days, 9.6 kg days
  - Optimized based on a flat extrapolation of known electron recoil backgrounds in the 2-7 keV window

Run Period	Starting Date	Ending Date	Raw Livetime [h]
1	August 18	August 29	166.5
2	September 7	September 14	111.2
3	September 18	September 25	105.9

CDMSlite – Analysis Cuts Overview

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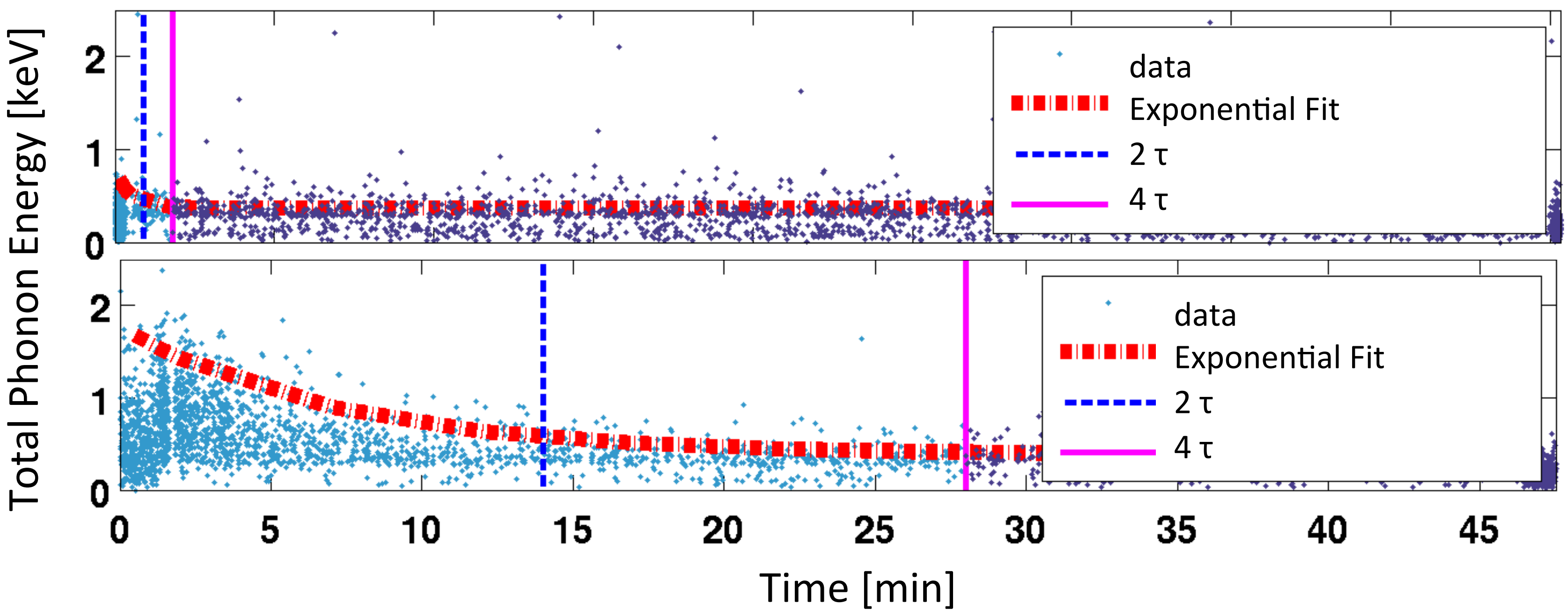
- Data selection cuts, time periods are used if
  - The leakage current is low
  - The gain can be well calibrated
- Event selection cuts, good events are
  - Not consistent with high frequency noise (“glitches”)
  - Not consistent with low frequency noise (microphonics)
  - Single detector energy depositions (anti-compton)
  - Not coincident with significant signals in the muon veto

CDMSlite – leakage current

- After biasing, leakage current was observed
- This current decayed on minute time scales
- The decay was fit and the initial noisy data were removed
  - This also removed very short data series



After biasing, a decaying leakage current was observed with 69V bias. The initial noisy period was fit with an exponential decay and events earlier than 4 time constants (solid magenta line) are cut. This typically cut 2-30 min from the 3 hour data series. The initial leakage current and signal gain are correlated.

CDMSlite – calibration

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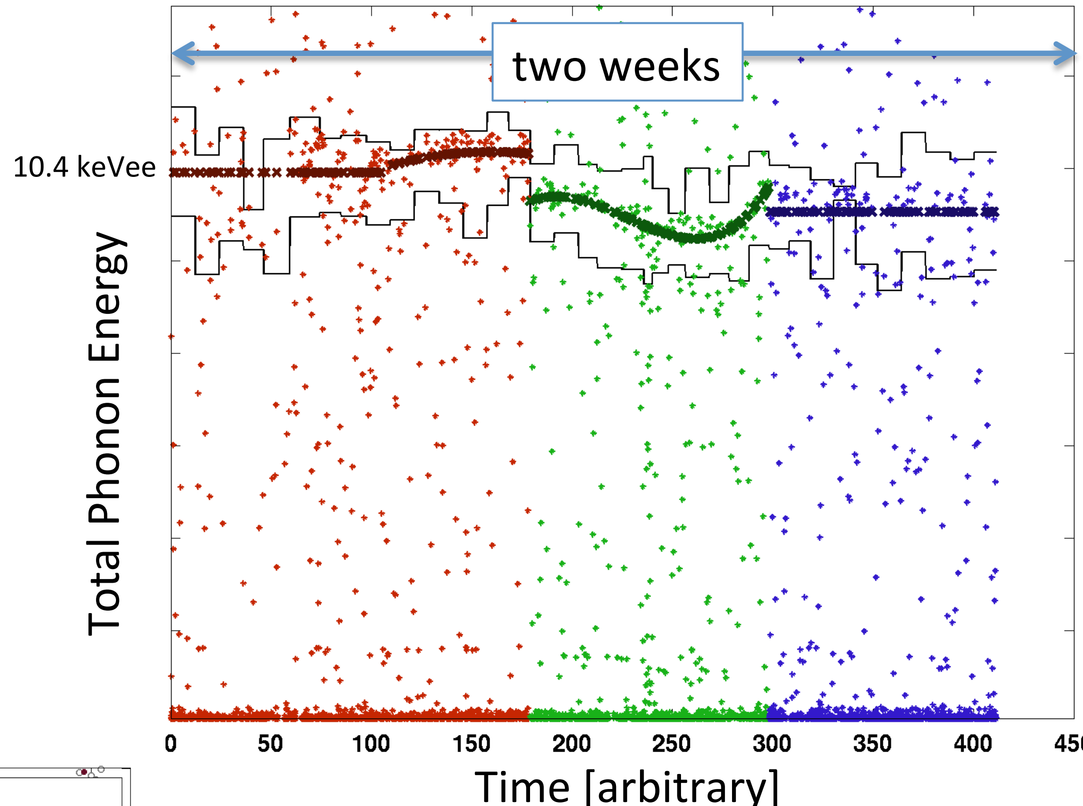
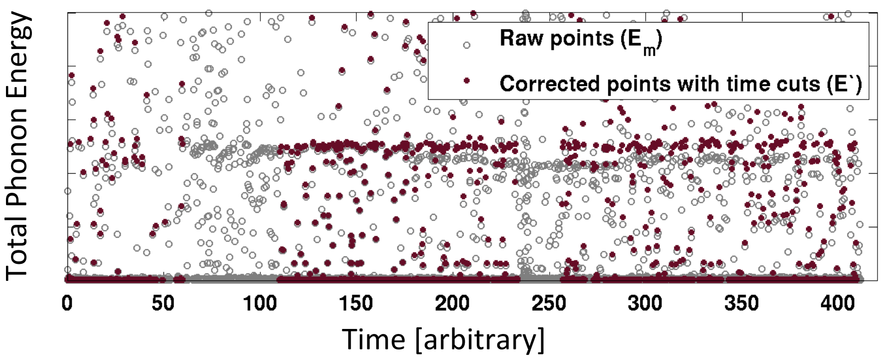
- The 10.4 keV from capture of the K-shell electron in ^{71}Ge was used to calibration the energy scale
- A slow drift of the gain was observed, so a time dependent gain calibration was implemented
- Periods with large dispersion in the 10.4 keV feature were removed



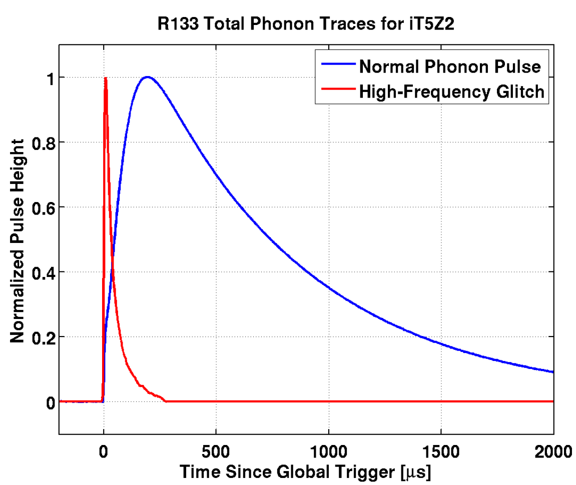


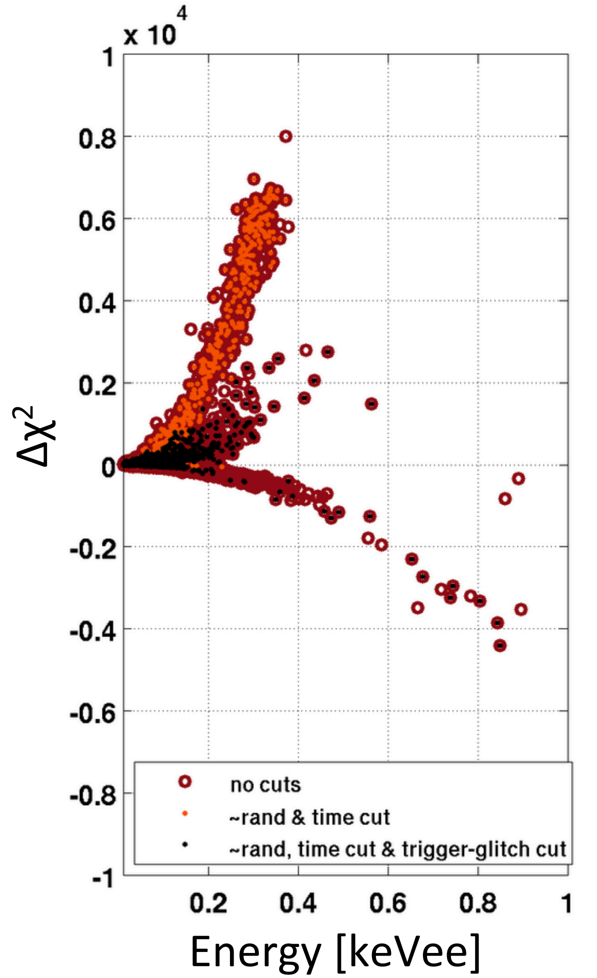
The 10.36 keV energy release from an L-shell capture in 71Ge was tracked through the run periods. The gain was observed to drift by ~10%. This time dependent calibration was applied to the data. Periods with large dispersion in the 10.4 keV feature were removed. The calibrated data used for the analysis are shown as solid (red) points in the left figure.

CDMSlite – event selection cuts

- There are two sources of noise that contribute to low energy events
  - **Electronic glitches**
  - Low frequency noise (likely microphonics)
- Cuts were constructed to remove these
- The efficiency of these cuts was high (~100%) for ionizing radiation
  - Measured both with monte carlo studies and ^{133}Ba calibration events
- Both cuts were based on the shape of the phonon events

Glitches are events with very fast rise and fall times. For large glitches, most detectors are effected. The events are believed to be due to fast transient currents through the TESs.





Electronic glitches were fit with two templates. The difference in the χ^2 is a useful metric to discriminate electronic glitches (at positive $\Delta\chi^2$) from physics events (at negative $\Delta\chi^2$)

CDMSlite – event selection cuts

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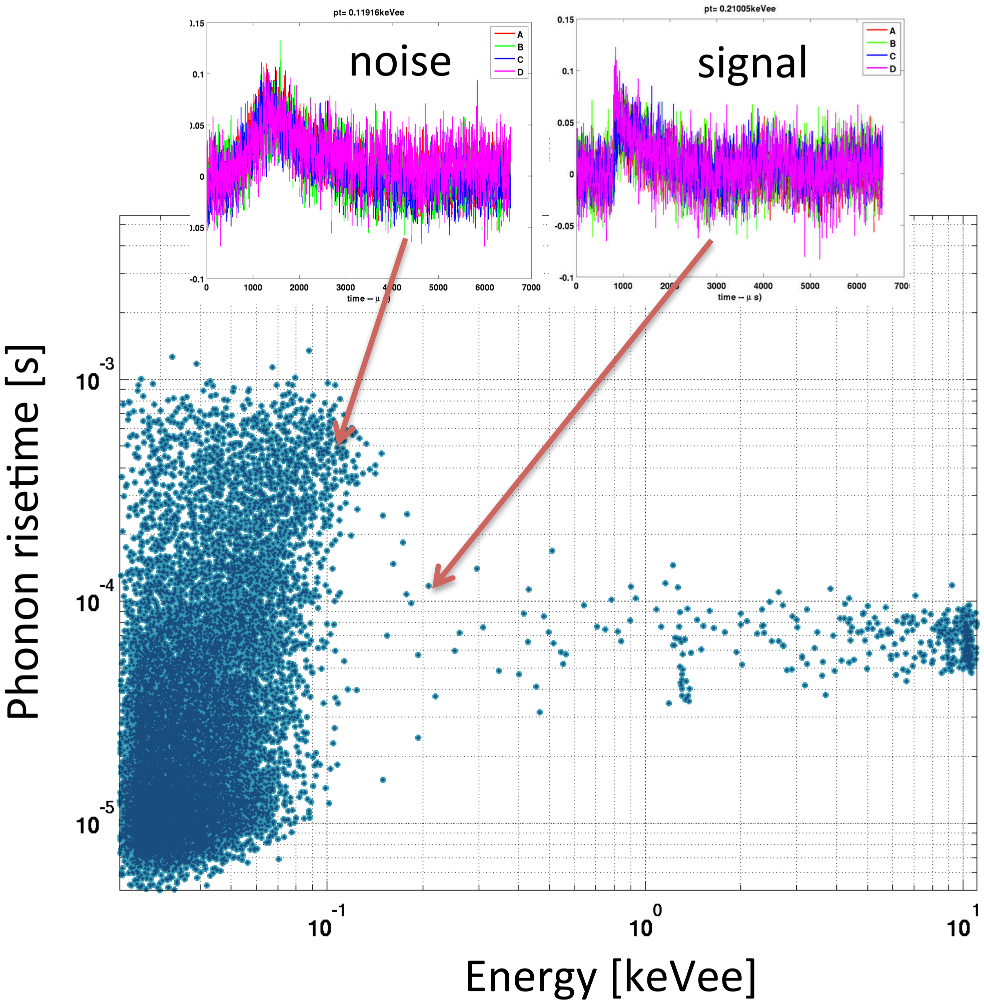


Low frequency noise was cut with a requirement that the rise time of the phonon pulse be consistent with that of ionizing radiation.

CDMSlite – Analysis Cuts Overview

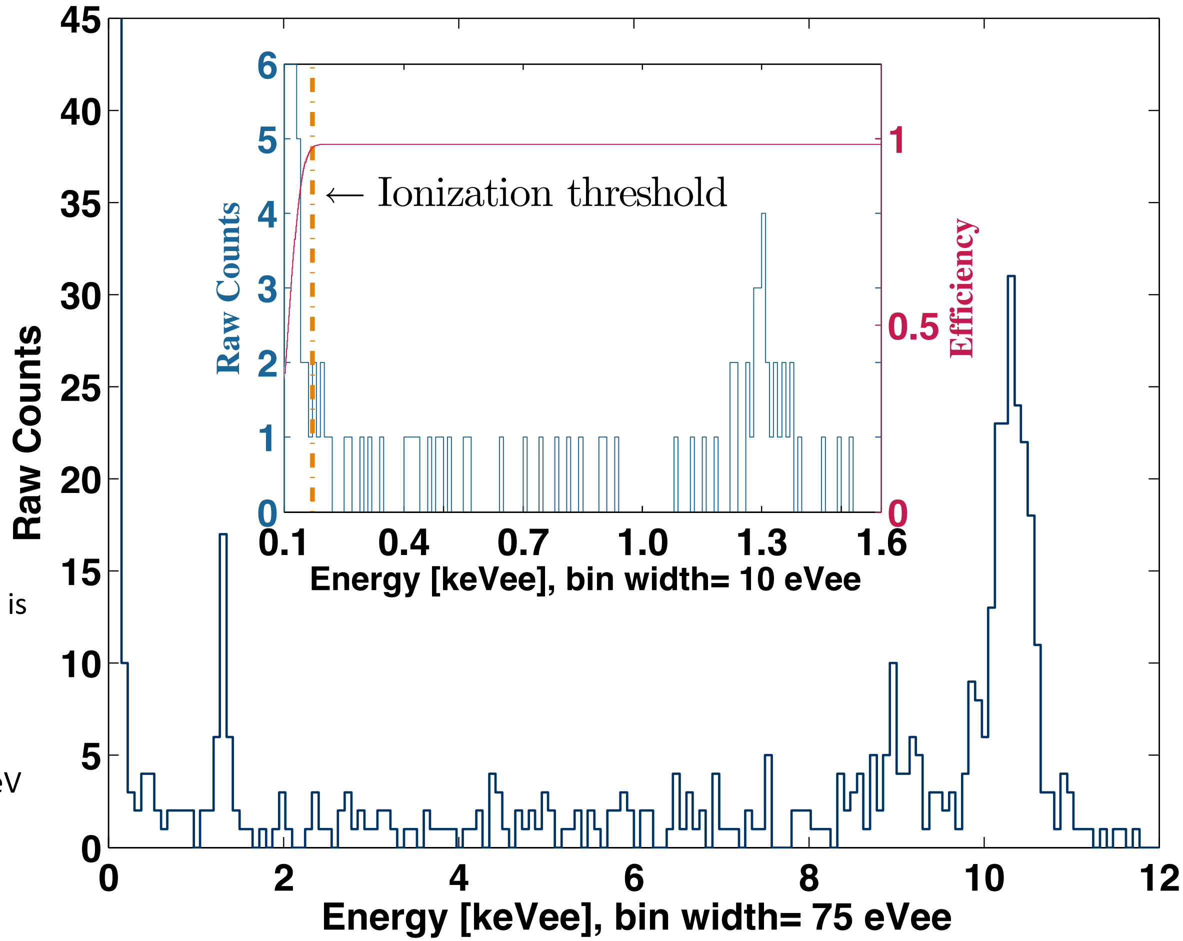
- Data selection cuts, time periods are used if
  - The leakage current is low
  - The gain can be well calibrated
  - **10.3/16 live days selected**
- Event selection cuts, good events are
  - Not consistent with high frequency noise (“glitches”)
  - Not consistent with low frequency noise (microphonics)
  - Single detector energy depositions (anti-compton)
  - Not coincident with significant signals in the muon veto
  - **98.5% efficiency for event energies >170 eVee**

CDMSlite – total efficiency

- Total exposure is 5.9 kg day

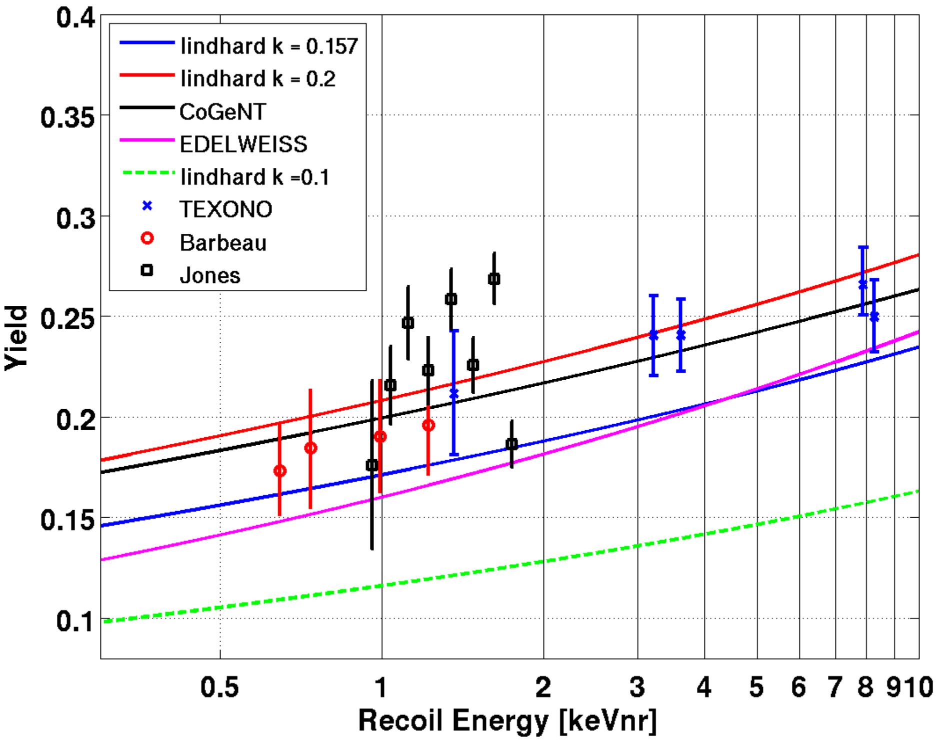
The combined acceptance of the event selection cuts is ~100% for energies above 170 eVee (shown in inset). The drop in acceptance at low energies is due to the hardware trigger.

The spectrum shows features at 10.36 keV and 1.3 keV due to K- and L- shell electron captures in 71Ge. The energy resolution of the 1.3 keV line is 43 eV (1σ).



CDMSlite – ionization yield of nuclear recoils

- Ionization measurements exist for nuclear recoils in the region of interest for this analysis
- Adopt the recommendation of Barker and Mei to use the traditional Lindhard model



A number of experiments have measured nuclear recoils in germanium over the relevant energy range. The Lindhard model (blue solid line) is used to interpret the CDMSlite spectrum. This figure was adapted from Barker and Mei (2012).

CDMSlite – final spectrum

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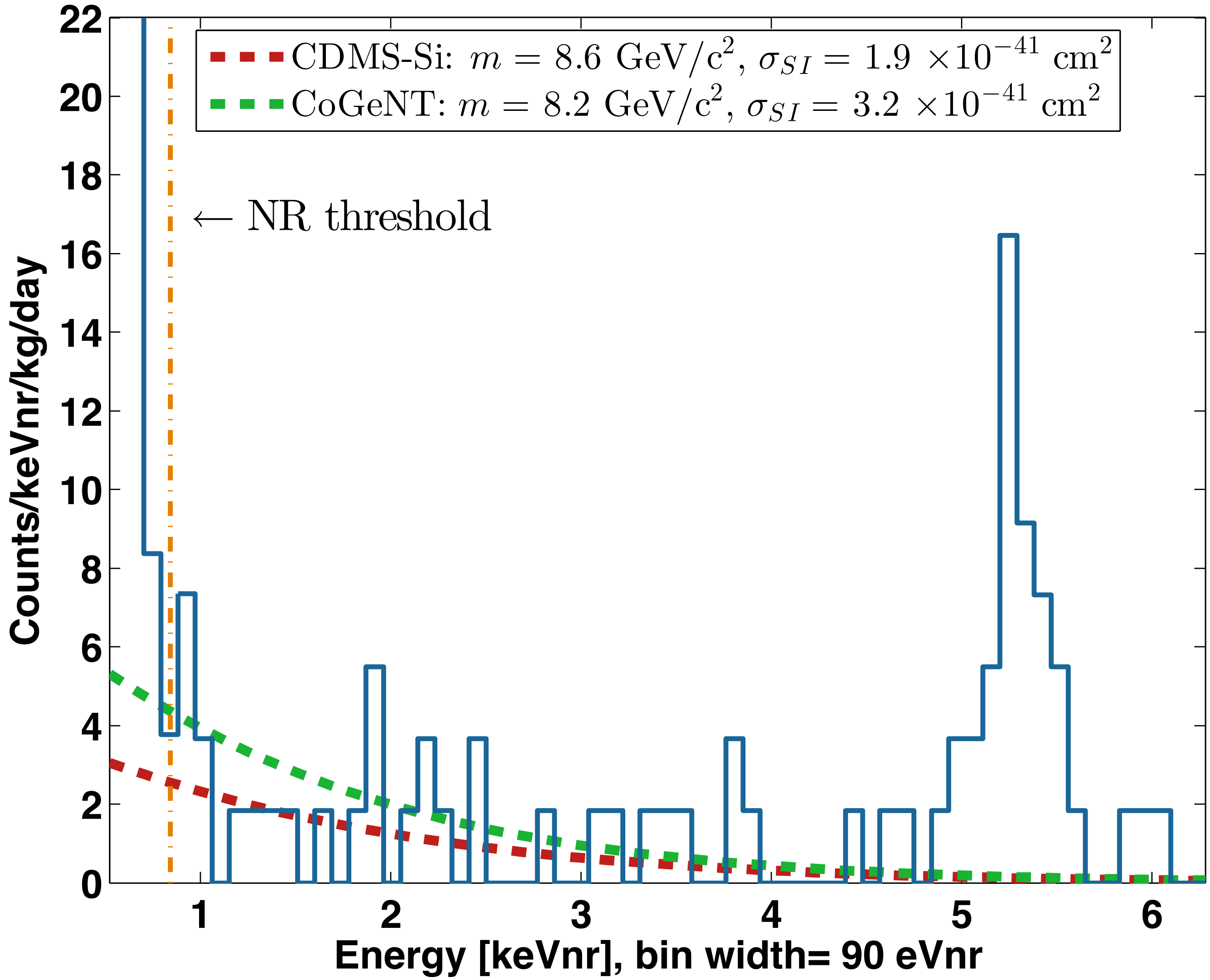

CDMSlite – Spin Independent WIMP-nucleon scattering limits

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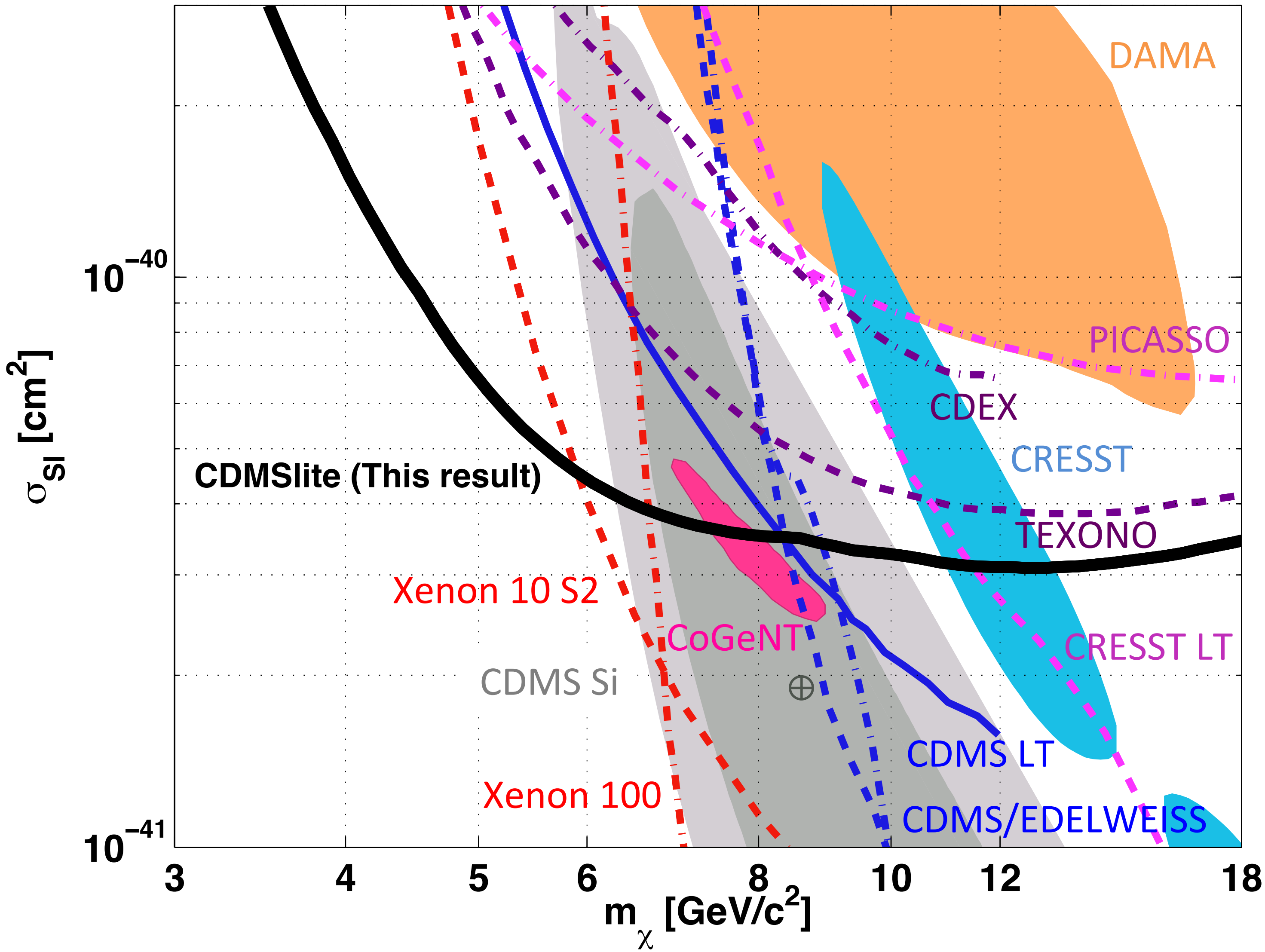
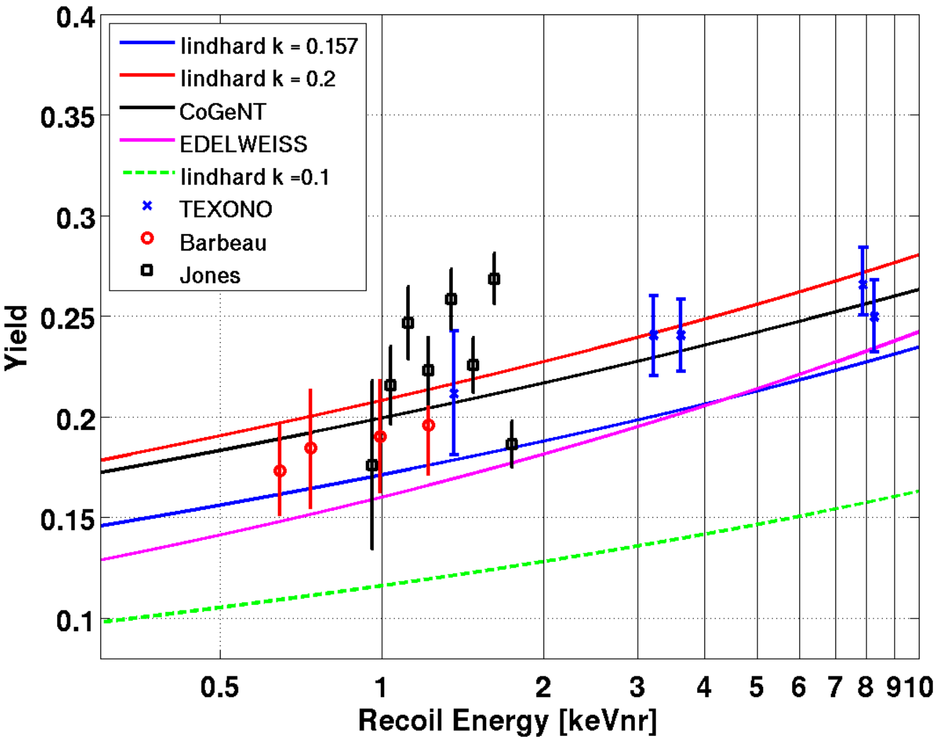


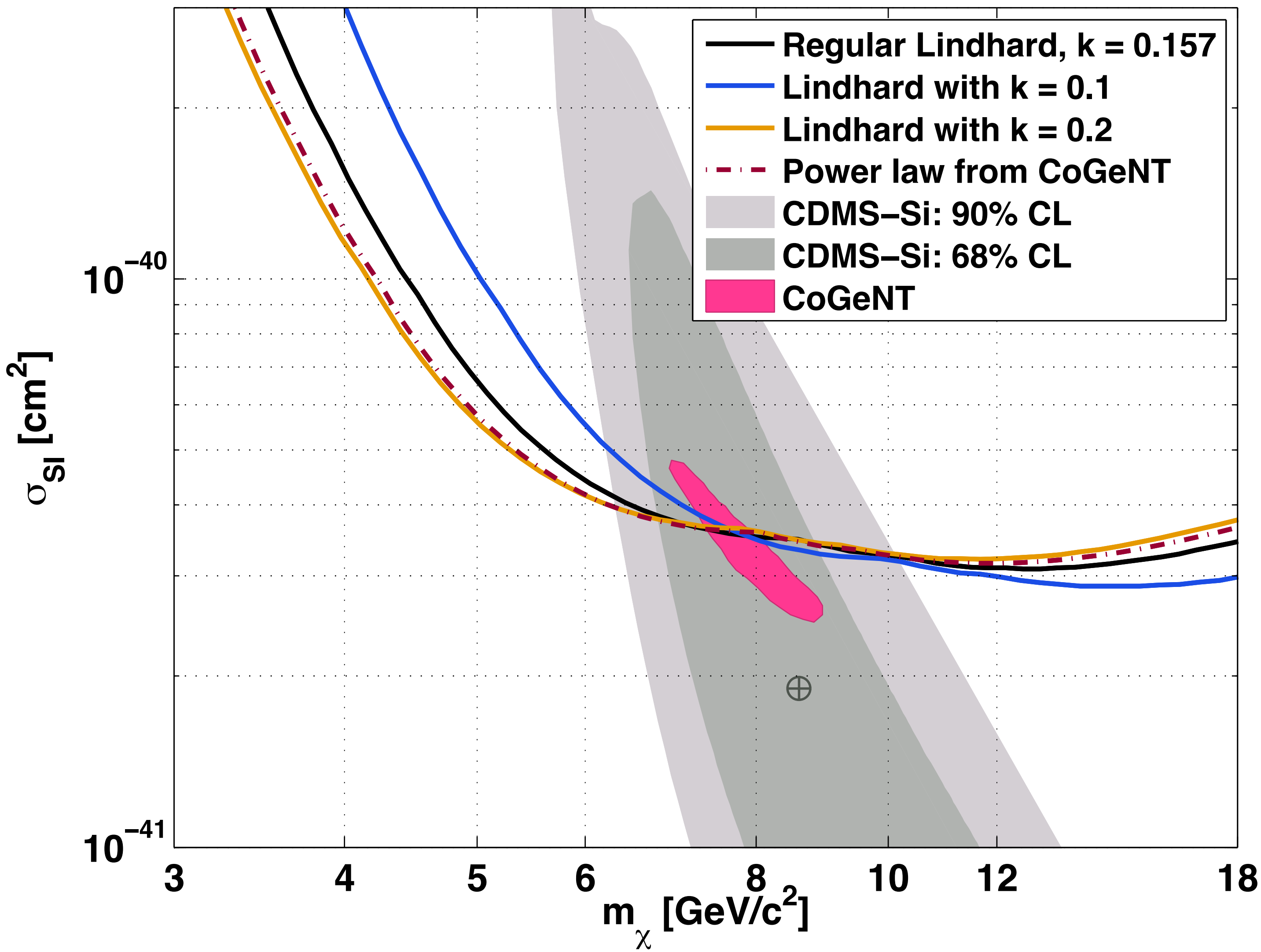
CDMSlite – ionization yield of nuclear recoils

- Ionization measurements exist for nuclear recoils in the region of interest for this analysis
- Adopt the recommendation of Barker and Mei to use the traditional Lindhard model
- To investigate this systematic, the large range of 'Lindhard-like' models of k=0.1 to 0.2 are used



A number of experiments have measured nuclear recoils in germanium over the relevant energy range. The Lindhard model (blue solid line) is used to interpret the CDMSlite spectrum. This figure was adapted from Barker and Mei (2012).

CDMSlite – yield systematic



Future prospects

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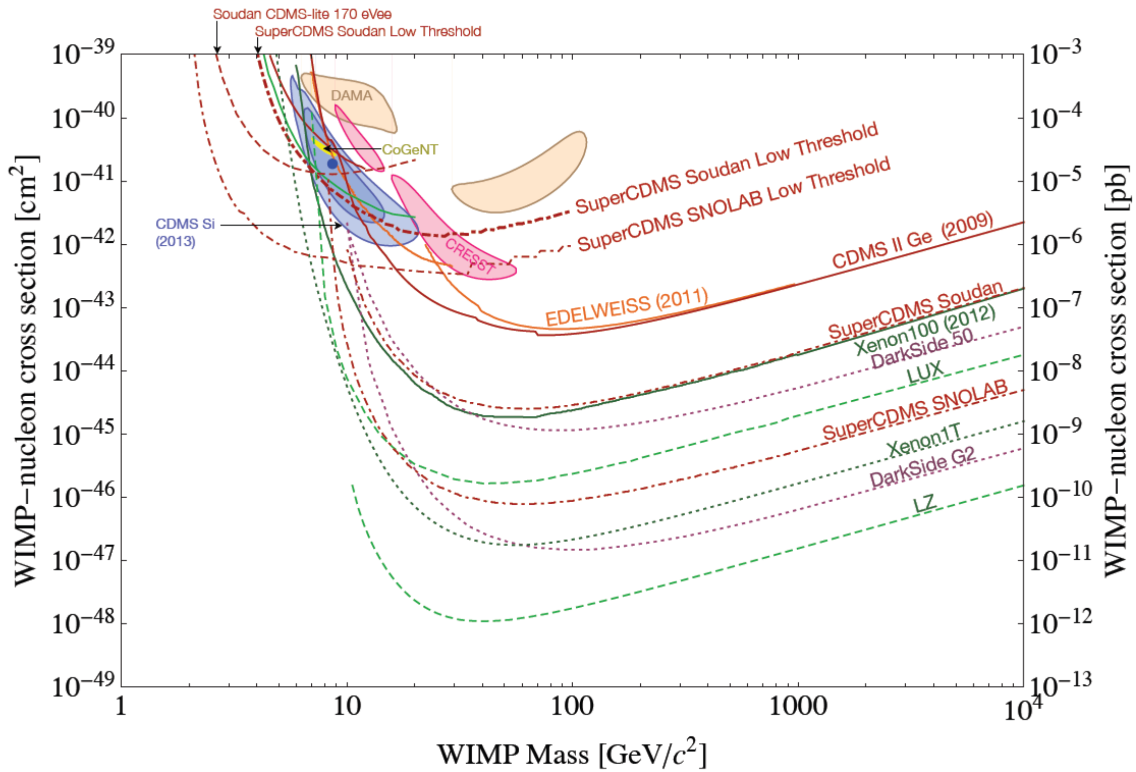
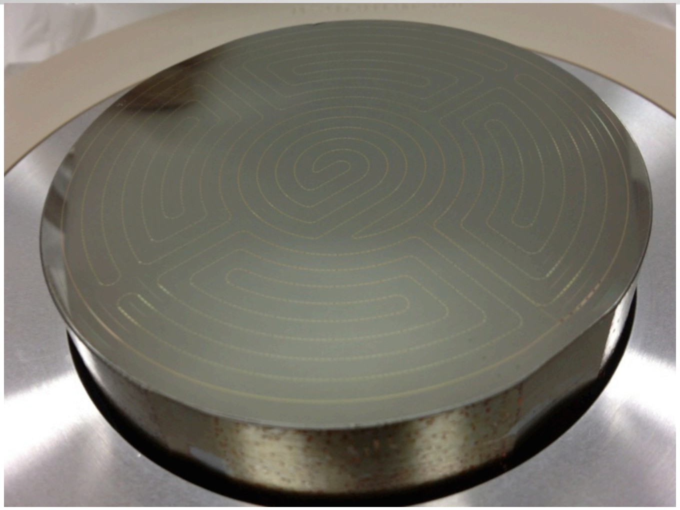
- A low threshold analysis at traditional bias voltages is ongoing with ~1.5 years of SuperCDMS-Soudan data
- Expanded CDMSlite dataset under discussion
  - Focused on understanding known backgrounds and searching for evidence of new backgrounds
  - More exposure for smaller statistical errors
- SuperCDMS-SNOLAB would have significant improvements
  - Cryostat designed for dramatically lower backgrounds
  - Deeper site reduces any residual effects of cosmic rays
- See J. Billard talk from Monday for more details



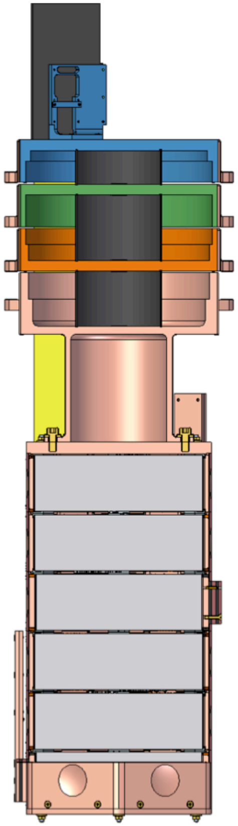
Projected WIMP sensitivity for SuperCDMS-SNOLAB after 3 calendar years.

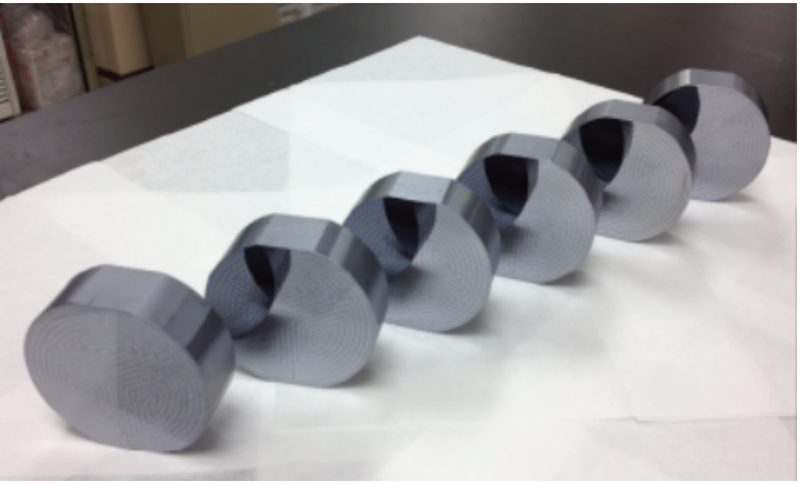
SuperCDMS-SNOLAB

- SuperCDMS has proposed a 200 kg cryogenic germanium array for the SNOLAB facility
- Projected spin-independent sensitivity of 8×10^{-47} cm^2
- See J. Billard talk from Monday for more details



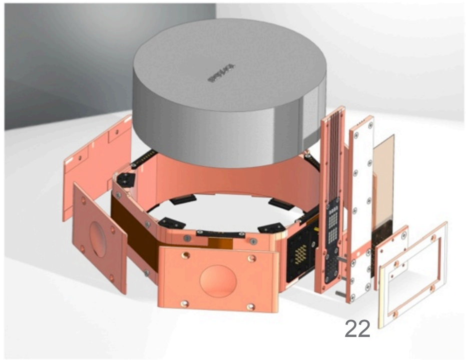
Procurement and performance testing of 100 mm x 33 mm germanium detectors is ongoing. 100 mm iZIPs have been fabricated. The proposed SuperCDMS-SNOLAB project involves fabricating and deploying 144 of these detectors.





Although not part of the 2013 R&D proposal, silicon detector fabrication is simpler and would add significant low mass sensitivity.

Cryogenic and mechanical prototypes of detector towers and crucial joints are in fabrication for final verification.



Conclusions

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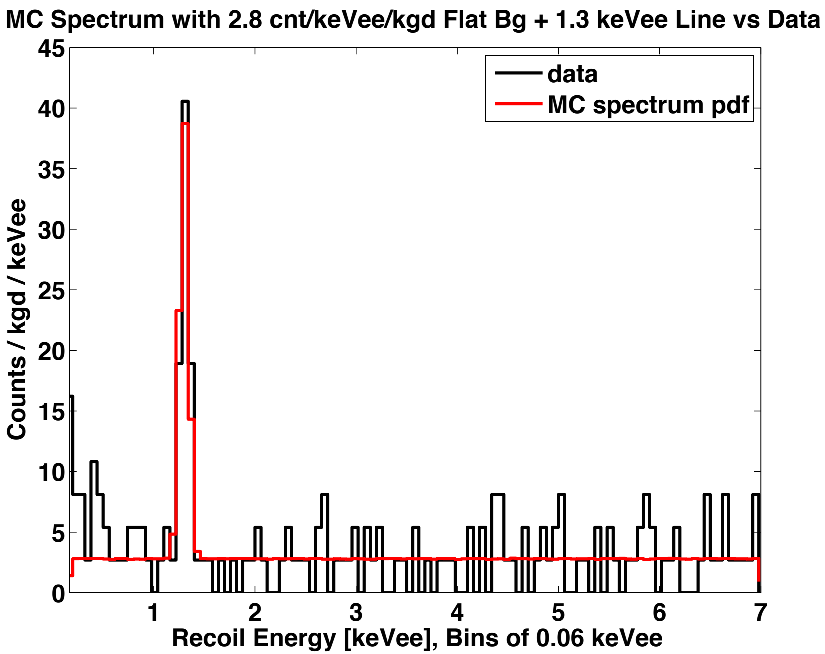
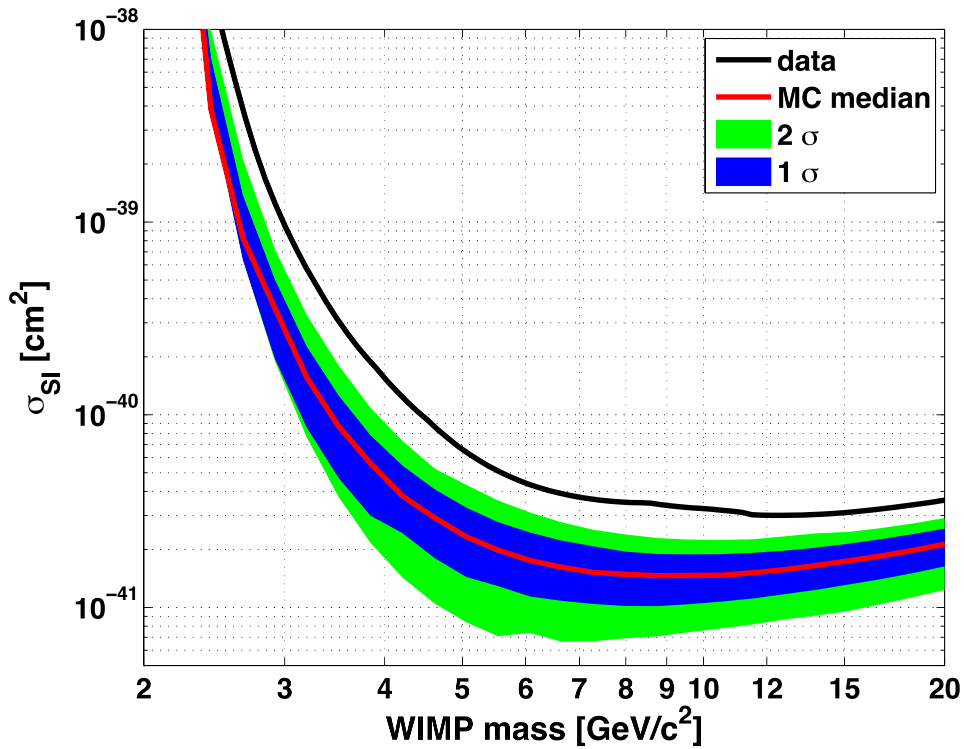
- The CDMS low ionization threshold experiment using voltage-assisted calorimetric ionization detection has produced initial results with a 170 eVee (0.8 keVr) analysis threshold.
- New limits on spin-independent WIMP-nucleon scattering cross-sections are produced based on an exposure of 5.9 kg day after all data and event selection cuts.
- A low threshold analysis of traditional iZIP SuperCDMS-Soudan data is ongoing with results expected soon. This analysis will have exciting sensitivity to low mass WIMPs.
- SuperCDMS-SNOLAB will have better sensitivity to low mass WIMPs because of better sensor design and lower backgrounds.

CDMSlite – backup

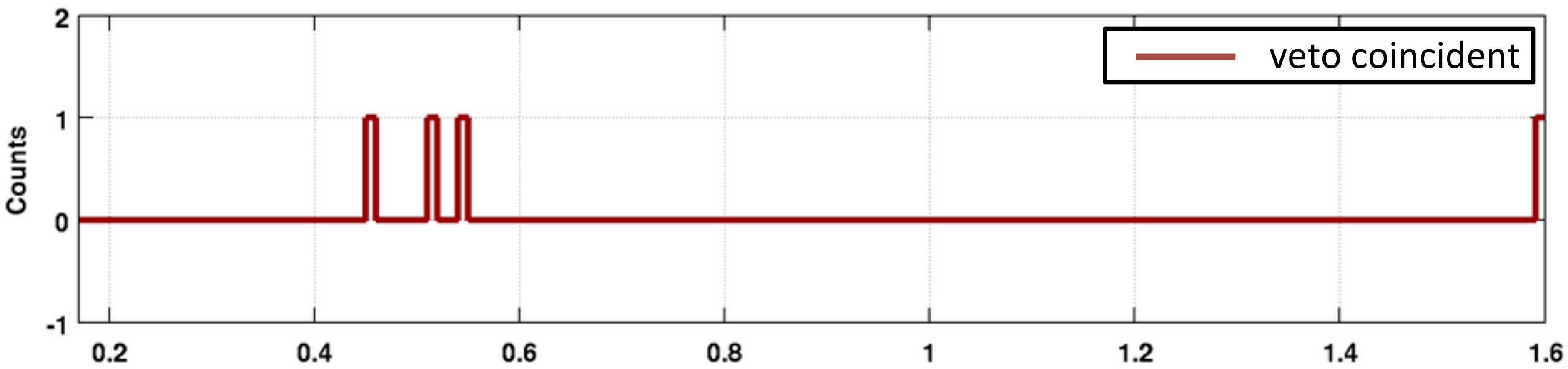


The blue spectrum was based on previous CDMS measurements of low energy electron recoil background rates. The red spectrum is based on extrapolating the CDMSlite spectrum from above the 1.3 keV L-shell capture line to below the line.



One and two sigma contours for limits from experiments thrown with the MC spectra in the figure to the left (red line.) The CDMSlite spectrum below the 1.3 keV L-shell capture line is more than two sigma higher than these flat extrapolations.

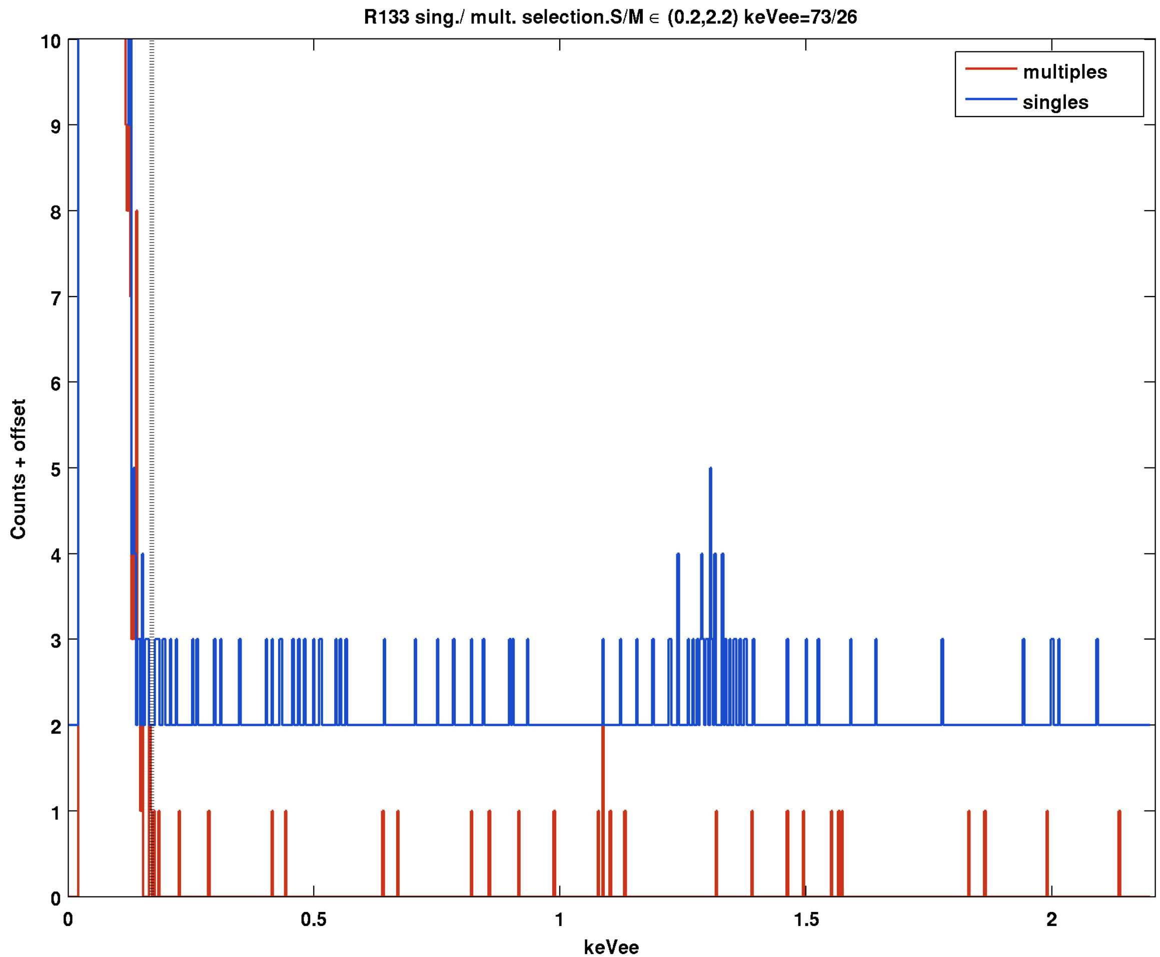
CDMSlite – veto spectrum



- Veto coincident data includes an interesting cluster at ~0.5 keVee

CDMSlite – singles cut

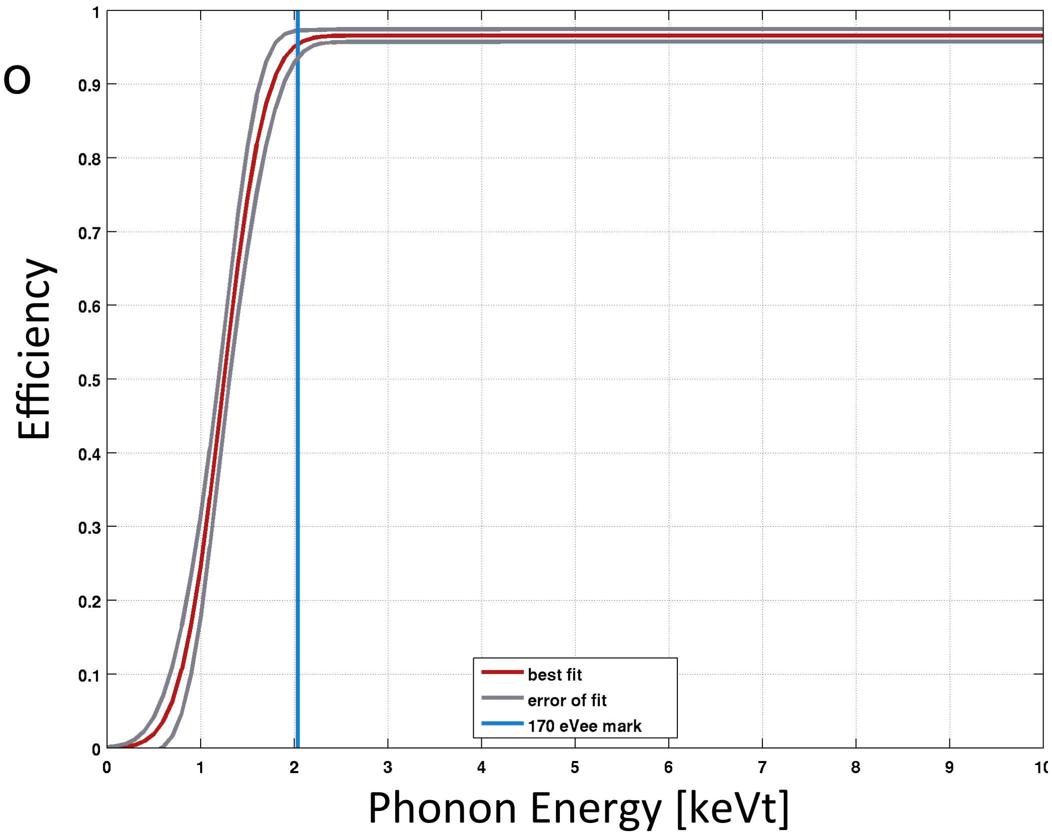
- Require that the signals in all other detectors is consistent with noise
- ~25% of events are coincident with events in other detectors



About 25% of events are coincident with activity in other iZIP detectors. Note that this cut is after data selection and noise rejection cuts. The veto cut has not been applied to these data.

CDMSlite – total efficiency

- An additional cut required that no significant energy was recorded in the 2” thick muon veto scintillator
  - 1.5% accidental coincidence probability
- Total exposure is 5.9 kg day
- Combined efficiency of event selection cuts is ~100% for energies greater than 170 eVee
  - 170 eVee is chosen as the analysis threshold



The combined acceptance of the event selection cuts is ~100% for energies above 170 eVee. Note the energy scale used here is calibrated to iZIP runs with 4 V bias. The drop in acceptance at low energies is due to the hardware trigger.